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(54) **Fiber Optic Intensity Modulator and an Optical Communications System incorporating such a Modulator**

(57) The invention describes a particularly advantageously constructed fiber optic intensity modulator with a light conductor with a D-shaped cross-section. The modulator is particularly suited for use in an optical communications system using a star configuration.

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Description

The invention concerns a fiber optic intensity modulator as described in the superordinate concept of patent Claim 1 as well as an optical communications system that contains such a modulator.

Such a modulator is, for example, the subject of a proposal for intensity modulation using a very high modulation frequency as described by J.F. Ryley and coworkers at the International Microwave Symposium, Brazil, July 1989 in the paper entitled "Proposed High-Speed on-fiber intensity modulator," Conference Reports, pp. 757-762.

In this connection Ryley *et al.* propose removal of the cladding material over the half of the circumference in the case of a multimodal fiber and applying on the exposed portion of the fiber core an initial internal electrode, an optically active layer of polymer material, and a second, external electrode. By means of the electrical field between the two electrodes the refractive index of the optically active material can be variably controlled, whereby the light-carrying capacity and thereby the attenuation of the fiber segment so-treated can be affected. A modulation signal applied to the electrodes thus results in an intensity modulation of the light traveling through the fiber segment.

The task of the instant invention is to provide a modulator of simple construction of the type described in the superordinate concept of Claim 1 of the patent.

The invention is described in Claim 1 of the patent. The other claims refer to advantageous embodiments and perfections of the invention as well as to optical communications systems implementing such modulators.

The modulator described pursuant to the invention is particularly simple to manufacture and to manipulate. The well-known processes used in the manufacture of D-type light conducting fibers, such as those used in polarizers, can be used [here] in the manufacture of the light conducting section having a D-shaped cross-section. The flat surface is particularly advantageous for the layout of the optically active materials and, if required, for additional layers, for example, for contacts. The manufacture of a D-type fiber is done by the extrusion of a fiber out of a suitably formed and constructed preform.

Optically active materials in the sense that the refractive index is variably controllable, are generally well-known. For example, thin film foils made of polymer after appropriate structuring are already being used as optical planar wave conductors. The molecular alignment is isotropic (disordered mode) in this case. If such foils are heated to a specific temperature, for example to 140°C, an anisotropic (ordered mode) can be created by a planar electrode layout and an appropriate electrical field. This forming is "frozen" in the cool-down

process and the foil becomes optically active in the sense that the refractive index can be influenced by means of an electrical field.

This will be explained in more detail using examples with reference to the figures. The figures are illustrative and generally not to scale. They show:

Figure 1: a cross-section through a modulator as described in the invention;

Figure 2: a longitudinal section through a layout using such a modulator and a light conducting fiber;

Figure 3: a planar layout with several modulators;

Figure 4: a cross-section through a modulator in the layout shown in Figure 3;

Figure 5: an optical communications system with intensity modulators.

In the case of the modulator shown in Figure 1 a photoconductor is provided with a core [1] and a sheath [2]. The photoconductor has a D-shaped cross-section, whereby the planar surface [20] of the sheath surface runs at a minimum spacing from the core [1], typically 1 - 3 µm. On the planar surface [20] there is a series of layers consisting of a thin interlayer [4], a layer made of the optically active material and a cover electrode [5]. The interlayer [4] is typically 100 nm thick and transparent for the intended operating wavelength. It consists of an electrically conductive material; for example SnO_2 or ITO and forms the counter-electrode to the cover electrode [5]. The light guiding properties of the photoconductor for light that is polarized perpendicular to the planar surface are essentially determined by the properties of the layer [3] made of the optically active material. For satisfactory light guidance; that is, minimum photoconductor end-to-end attenuation $n_3 < n_k$ with n_3, n_k being the refractive index of the layer [3] and the core [1], respectively. For the purpose of balancing the refractive index both a material with sufficiently low refractive index can be used with the use of standard photoconductor fiber material can be used for the photoconductors {1, 2], for the layer [3] or, with the used of the currently more common optically active material with refractive indices of $n_3 = 1.55 .. 1.6$, a core material can be selected; for example GeO_2, with a correspondingly higher refractive index n_k.

Using an electrical field between the electrodes [4 and 5] the refractive index n_3 can be increased to $n_3 > n_k$, whereby the optical wave from the core region breaks out and the end-to-end attenuation increases ("dark modulation"). The attainable modulation hike between minimum and maximum end-to-end attenuation is high and lies in the area of, for example, m = 80%.

The construction is in principle identical for optically active materials whose refractive index without field is greater than n_k and on application of a field can be decreased to below n_k.

Advantageous process steps for the manufacture of the modulator such as, for example, vapor deposition techniques for the transparent interlayer, coating techniques for polymers (spraying, dipping), structuring processes (plasma etching, ion-beam etching), etc. are familiar enough from the state of the art and will therefore not be discussed in detail.

In the layout shown in Figure 2 the modulator extending over the length A in the order of 1 cm is shown as consisting of a core [1], a sheath or cladding [2], electrodes [4, 5] and an optically active material [3] in conjunction with a photoconducting fiber with a core [1'] and cladding [2']. The cores [1, 1'] of the modulator and the fiber optic are aligned. The modulator is executed as a reflecting modulator with a reflector [6] at one end. In transmission operation of the modulator the reflector [6] is eliminated and an optical element is provided at both sides of the modulator, preferably one light guide fiber each. The gap between the modulator and the light guide fiber can be filled with solder glass using the conventional method.

The combination of a fiber optic modulator in conjunction with incoming and outgoing light guide fibers is particularly desirable because of the possibility of easy alignment and the low coupling losses. Precise alignment can be done simply by insertion of the modulator-light guide and the light guide fiber into a V-shaped groove running through a mechanically stabile carrier; this can be more clearly seen in Figures 3 and 4.

Figure 3 shows a layout with several modulators whose flat surfaces lie in one plane. The photoconductor of the modulators are placed into V-shaped grooves [9] of the carrier structure [7], which are also provided to accommodate incoming and outgoing photoconductor fibers. Figure 4 illustrates in detail the position of the photoconductors with sheath/cladding [2] and core [1] in the grooves [9].

A carrier plate [8] made SiO_2 glass, for example, carries "imbedded" on its underside the cover electrodes [5] for the individual modulators and the individual accesses [50] to the cover electrodes as well as the optically active material [3] as a total-surface layer and the thin, electrically conductive interlayer [4] as a counter electrode to the individual cover electrodes [5] that serves in common all of the modulators. The support plate [8] is situated on top of the flat upper surface of the support structure [7] and the co-planar flat surfaces of the photoconductors lying in the grooves, such that the layer structure of the modulator is produced as described in detail in Figure 1. A monocrystalline silicon substrate with 100-crystal surface is suitable as the support structure. The grooves can then created using a high precision and simple method by means of an anisotropic etching technique that takes advantage of the crystalline orientation. In an alternative to the illustrated layout using a support structure, the layers [3, 4] and the cover electrode [5] together with the leads [50] can also be separated on the substrate [7] with the photoconductors situated in the grooves [9].

An important characteristic of the modulator described in the invention is the polarization selectivity, since essentially only those components of the light conducted by the photoconductor situated perpendicular to the

flat surface, are modulated. Thus, the polarized components that are parallel to the flat surface remain unmodulated or, preferably, are modulated by another polarizer with a flat surface rotated 90°, whereby modulators with planar surfaces turned counter to one another can be operated independently of one another. In this way, in one light path or in a network of light paths, light waves having orthogonal polarization can be used simultaneously [by] employing independent modulation and thus the transmission capacities are doubled. At the time of transmission maintenance of polarization must be assured, for example, by the use of monomodal fibers that maintain polarization. The modulators are particularly suited for use in optical communications systems and can replace modulated active elements, for example semiconductor lasers. An advantageous construction of one such optical network is illustrated in Figure 5.

Fiber optic networks in local distribution ranges (LAN, e.g. office communications, plant control, antonomous [*sic*] systems are frequently characterized by a number of electro-optical interfaces [subscriber connections]. Because of the short line-lengths [cabling segments] (L > 1 km) the costs are determined not by the distribution network but by the terminals. Because of the short lengths there are only minimal line attenuation; that is, the optical flows lie at a respectively high level. If one considers the optical performance budget against the standard of conventional transmission performances or reception sensitivities, then a surplus in optical performance in such network structures is found. This performance reserve can be utilized to drastically reduce the number of optical transmitters in the network. Since the precision coupling of laser photoconductor fibers represents an important portion of the cost of a terminal, considerable savings can be realized with a high number of terminals if, instead of several modulated light sources, one single light source in conjunction with several modulators are used, whereby the light source -- preferably a laser -- is received initially unmodulated. Because of their low minimal end-to-end attenuation of < 1 dB the modulators described are suitable for this type of network configuration. Preferably the reflecting modulators (see the discussion relating to Fig. 2) would be used.

The assumption is made of an optical star-type network [N1] with a passive monomodal star-type coupler [SK]. As the light source only a single semi-conductor laser [H] is planned for the entire network and will supply all of the subscribers [T1 ... T10] over bi-directional connections [B] uniformly with unmodulated light via a star-coupler. The light fed via the connections [B] into the subscriber equipment will be fed into a reflecting modulator [M].

An active subscriber device reflects modulated light via the connection [B] to the star-coupler [B] where it is uniformly divided into the receiver lines [E] and supplied to all subscribers via receiver connections [I] to optical receivers (photodiodes). Each subscriber can reach every other subscriber without himself inputting light into the network by way of an active light source. Particular benefits of the illustrated embodiment are:

1. Because of the low optical levels there is no optical reaction on the laser (preferably a single-mode laser).

2. The cost-intensive laser-fiber coupling occurs only once.

3. Because of the low optical levels the transition to additional star networks is possible even without a laser transmitter but only with LED's (Figure 5 implies an additional network N2, transceiver with link manager, photodiodes [P] and light emitting diodes LED).

4. By additional modulation of the central semiconductor laser [H] the transition can be made from decentralized, nondeterministic operation to central operation with assignment of access rights (token passing, deterministic operation).

The optical communications system can furthermore be of use in a radar antenna array with active transmitters as the control network for transmission of modulated HF signals to the elementary aerial as well as in an aerial LIDAR system for direct aerial input to the extent the low transmitted output is sufficient in the particular area of application.

Patent Claims

1. A fiber optical intensity modulator consisting of a photoconductor section in which the cladding material is in part replaced by optically active material, whose refractive index is variably controllable and which is and **characterized by the fact that** the photoconductor-segment exhibits a D-shaped cross-section with a planar surface [20] lying parallel to the longitudinal axis of the photoconductor and that the active material [3] is arranged on the planar surface.

2. A modulator as described in Claim 1 and **characterized by the fact that** the active material is controllable by means of an electrical field, that an electrically conductive transparent interlayer [4] between the planar surface [20] and the active material [3] forms an initial electrode and the second electrode [5] is arranged on the active material, and that the electrical field lies between the two electrodes.

3. A modulator as described in Claim 1 or Claim 2 and **characterized by the fact that** several modulators are provided with a planar surface lying on a single plane and one of the electrodes is executed so as to serve as the common electrode for all modulators (Fig. 3).

4. A modulator as described in one of the Claims 1 to 3 and **characterized by the fact that** the active material and, if required, the electrodes are arranged on a mechanically stabile support plate [8].

5. A modulator as described in one of the Claims 1 to 4 and **characterized by the fact that** the optically active material is a polymer.

6. A modulator as described in one of the Claims 1 to 5 and **characterized by the fact that** the photoconductor [*lit.* "light guide"] is a single-mode glass fiber.

7. A modulator as described in one of the Claims 1 to 6 and **characterized by the fact that** one end of the photoconductor is reflective [6].

8. A modulator as described in one of the Claims 1 to 7 and **characterized by the fact that** the photoconductor segment together with one or two fully-clad/fully-sheathed photoconductors are arranged in a V-shaped groove [9] of a mechanically stabile support [7].

9. A modulator as described in one of the Claims 1 to 8 and **characterized by the fact that** two photoconductor segments are arranged one behind the other with their planar surfaces turned 90° relative to one another in the light path and are controllable independent of each other.

10. An optical communications system with photoconductors and at least one light source and **characterized by** the use of at least one fiber optic modulator particularly one as described in one of the foregoing Claims.

11. A system as described in Claim 10 and **characterized by the fact that** a network with a star-configuration is used.

12. A system as described in Claims 10 and 11 and **characterized by the fact that** that the modulator is executed as a reflecting modulator with a bi-directional connection photoconductor.

13. A system as described in one of the Claims 10 to 12 and **characterized by the fact that** that it concerns a control system for a radar antenna array with several modulators.

14. A system as described in one of the Claims 10 to 12 and **characterized by the fact that** it concerns an input system for a LIDAR antenna array configuration.

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3 Pages of Drawings are Attached

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FIG. 1

FIG. 2

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FIG. 3

FIG. 4

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FIG. 5